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TEST OF NUWC SHARK ATTACK DETERRENT DEVICE

By Albert L. Tester Gareth J. Nelson
Charles I. Daniels
University of Hawaii,
for the
Research and Engineering Department

June 1968

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NAVAL UNDERSEA WARFARE CENTER

An activity of the Naval Material Command

G. H. Lowe, Capt., USN
Commander

Wm. B. McLean, Ph.D.
Technical Director

This study is one in a series on the shark attack deterrent device (shark screen) developed at this Center. The work was originally undertaken by the Naval Ordnance Test Station, China Lake, Calif. In July 1967, research in the area of shark deterrents was transferred to the newly created Naval Undersea Warfare Center, following a reorganization of Navy laboratories. Financial support was provided by independent exploratory development funds from the Bureau of Naval Weapons under Task Assignment IED-R3601-00-000/216-1/F008-98-1b.

The report was prepared by the University of Hawaii, and has not been given additional editorial treatment.

[redacted]

Under authority of
Wm. B. McLEAN
Technical Director
14 June 1968

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CONTENTS

INTRODUCTION

A plasticized bag has been designed by Dr. C. Scott Johnson, U. S. Navy Marine Biology Facility, Point Mugu, California, to support a person when the bag is full of water and buoyed by three inflatable cuffs attached to its top. The bag should prevent the release of blood and other shark-attracting odors into the surrounding water. The questions arise as to whether sharks in the area will attack or damage the bag and what is the best material, color and size of bag to minimize shark attack.

The purpose of this work is to determine the response of both captive and free-living sharks to bags of two sizes and of various colors (a) when the sharks are not motivated by food, (b) when they are motivated by food, and (c) when motion is imparted to the bag simulating the movements of a person within it. Any other information concerning the suitability of the bags as an anti-shark device will also be noted.

The tests were conducted on captive sharks at the Hawaii Institute of Marine Biology (HIMB), Coconut Island, Oahu, and on free-living sharks at the Eniwetok Marine Biological Laboratory (EMBL), Eniwetok Atoll, Marshall Islands. We are indebted to Mr. V. E. Brock, Director of HIMB, for use of pond facilities at Coconut Island, and to Dr. R. W. Hiatt, Director of EMBL, for the use of laboratory facilities and for logistic support during our work at Eniwetok. Dr. C. Scott Johnson provided some of the equipment and also the services of Mr. Morris Winterman for assembling it at Eniwetok. We are grateful to all who assisted in the work, including Lt. Col. Louis Montalvo, Commanding Officer of the Eniwetok Missile Range Facility, and many personnel of Holmes and Narver, Inc., including Mr. W. Willard, Mr. J. Gabbard and many others.

SECTION I - POND TESTS

MATERIALS AND METHODS

Facilities, Sharks, Apparatus.

The first tests were conducted in a large, semi-natural pond at the Hawaii Institute of Marine Biology during January and February, 1966. The pond has screened gates at one end and a screened fence at the other, and is flushed by tidal action (Fig. 1).

Two grey sharks, *Carcharhinus milberti* (identification fairly certain but not confirmed), one about six feet and the other about seven feet in length were used. They had been in captivity for six years and were active, healthy specimens. They were starved approximately for two months before the tests were conducted.

The sharks were confined in a section of the pond approximately 200 feet long and 75 feet wide. One side of the pond was relatively shallow over its entire length with an average depth of about two to four feet, depending on the tide. The other side contained a channel with an average depth of 8 to 10 feet, depending on the tide. The average width of the channel was about 20 feet. It had a sandy bottom and coral-head sides. The sharks usually swam slowly back and forth along the channel, with an average speed of about one foot per second (1.2 miles per hour).

A 16-foot observation tower was erected halfway along the length of the area, overlooking the channel. A 50-foot test area, 25 feet on either side of the tower, was marked off by strings running across the pond (Fig. 1). A portable tape recorder was used to describe shark activity by one of two observers on the top of the tower while experiments were in progress. The other observer simultaneously diagrammed the movements of the sharks during control and test periods of most experiments.

Bags.

All pond tests were conducted with two plasticized bags 37 inches in diameter when inflated by means of the three cuffs at the top. One bag was pink and made of a light-weight, smooth, plastic-like material.

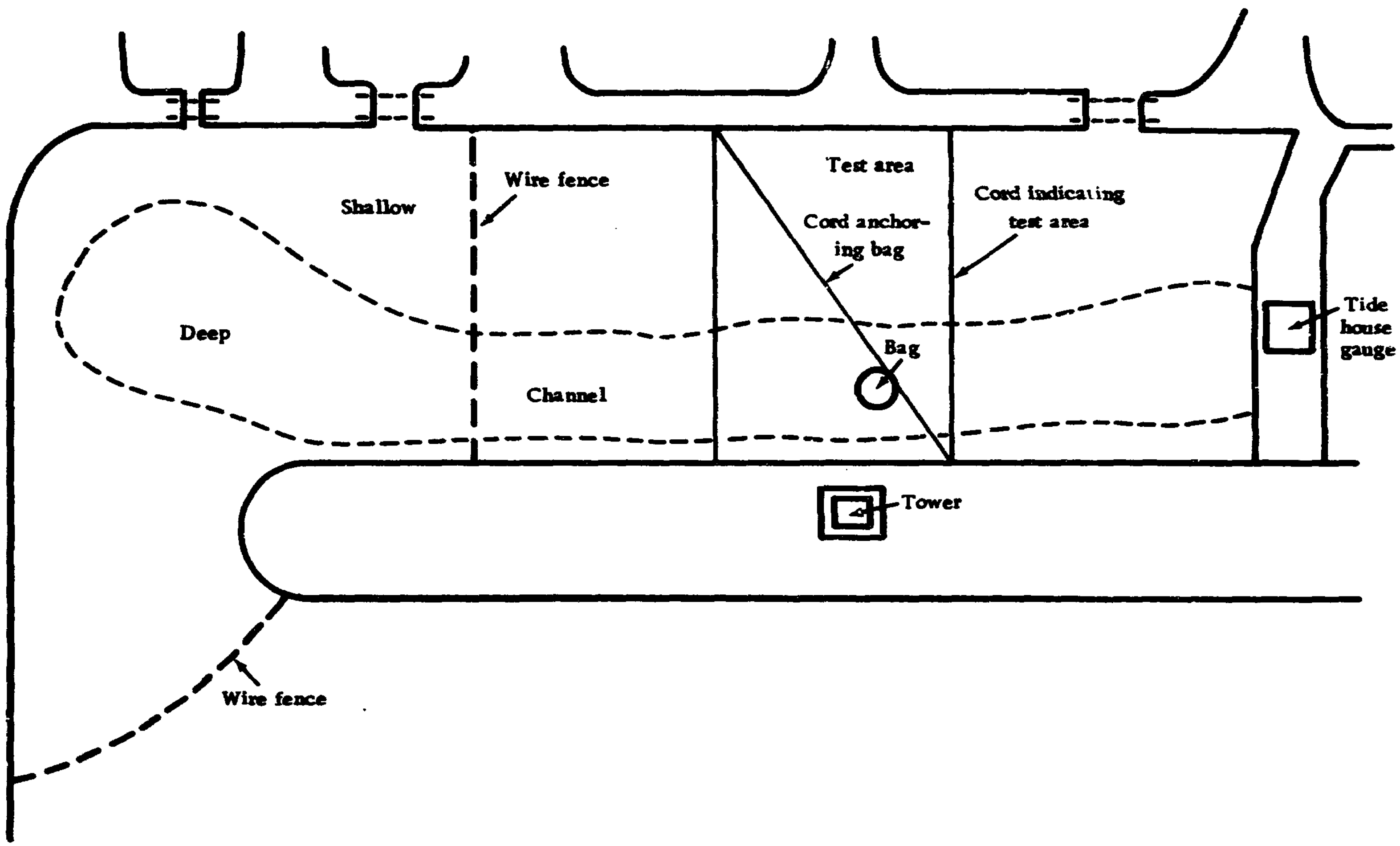

FIG. 1. Pond No. 5 at the Hawaii Institute of Marine Biology Showing Experimental Arrangement.

The other was grey (silvery) and made of lighter-weight, fabric-like material. The pink bag was translucent and the grey bag opaque. Reflectivity (see later) was not measured. These bags, unlike those used in the lagoon tests, had a grommet hole in the side just below the cuffs. The hole, used for securing the bag to a line, was covered with a plastic sleeve.

Experimental procedure.

In most of the experiments (P1 to P4, Table 1), the paths of the sharks through the test area were diagrammed and the number of passes through or loops into the area were recorded during three 5-minute control periods. A bag with cuffs inflated and filled with water then was moved into mid-channel and held in position by means of a cord fastened to the bag and running across the pond. The response of the sharks to the bag was then diagrammed and recorded during three 5-minute test periods, followed by a further period of continued observation.

In some experiments (P2, P4, P6) the water adjacent to the bag then was chummed with small whole fish (smelt, butterfly fish) or pieces of cut fish (surgeon fish, eels, etc.) to induce the sharks to feed as close as possible to the bag. In other experiments whole, slashed fish (one surgeon fish in P4; 2 surgeon fish and 4 butterfly fish in P5 and P7) were tied to the bag from a loop of string around the inflated cuff such that they were equally spaced and dangled against the side of the bag about 8 to 12 inches below the surface. After the response of the sharks was observed, chum then was thrown as close as possible to the bag to see if the sharks would take the attached fish.

Table 1. Experiments conducted at Hawaii Institute of Marine Biology, January and February, 1966.

Exp. No.	Date	Time	Bag	Experimental Condition	Av. No. Passes/5 min.	Remarks
P1	1/4	0850-0915	-	Control	8.0	Straight passes.
		0955-1012	grey	No chum	3.0	Veered around bag or looped short.
		1012-1100	"	"	0.4	Circling in end zone; passes in shallows.
P2	1/4	1221-1236	-	Control	5.0	Straight passes, one loop.
		1300-1317	pink	No chum	2.7	Veered around bag or looped short.
		1317-1407	"	"	0.8	Mostly circling in end zone.
		1410-1500	"	Chum added	—	Circling bag; a few contacts.
P3	1/6	0855-0916	-	Control	7.0	Straight passes.
		0939-0954	pink	No chum	6.3	Veering around bag.
		0954-1020	"	"	4.3	Slight veering; deep swimming.
P4	1/6	1147-1209	-	Control	5.3	Straight, deep, slow passes.
		1232-1249	grey	No chum	6.0	Veering around bag; deep passes.
		1249-1304	"	"	4.0	Slight veering; deep passes.
		1315-1330	"	Chum added	—	Circling bag; a few contacts; bag ripped.
		1330-1350	"	Fish tied to bag	—	Circling but no contacts.
		1350-1400	"	Chum added	—	Excited circling; contacts; one fish taken.
P5	2/1	0907-0926	-	Control	6.3	Straight passes.
		1047-1110	pink	Fish tied to bag	—	Circling but no contacts.
		1120-1200	"	Chum added	—	Excited circling; a few contacts.
P6	2/22	1100-1120	grey	No chum	—	Veering around bag; deep passes.
		1120-1200	"	Chum added	—	Excited circling; no contacts; movie sequence.
P7	2/22	1410-1416	pink	Fish tied to bag	—	Deep passes; no response.
		1416-1432	"	Chum added	—	Excited circling; many contacts; one fish taken; movie sequence.

RESULTS

The results of the experiments (P1 to P7) are summarised in Table 1. They were conducted during the morning or early afternoon with underwater visibility excellent (P1 and P2), fair (P3, P5, P7) or poor (P6). Noon water temperature, measured only once but not subject to wide variation, was 75 deg. F.

Behavior during Control Periods.

Under normal (control) conditions, the sharks swam slowly back and forth along the channel, averaging 5 to 8 passes per 5-minute period. Only rarely did they swerve from a straight course down the channel and only once were they seen to loop, i.e., reverse direction of swimming while in the test area. They tended to swim in mid-water or near the bottom of the channel. Their paths during the three 5-minute control periods for one experiment (P2) are illustrated in Fig. 2.

Response to the bags.

When a bag was introduced, the sharks seemed to see it as soon as they entered the test area. At first they would loop out of the area when within a distance of about 15 feet from the bag. Soon, however, they would pass through the area, but would either veer around the bag maintaining a distance of about 10 feet from it, or they would pass over the coral heads lining the sides of the channel. Occasionally they would pass through the test area in the shallows. The change in swimming pattern during test periods is illustrated in Fig. 2.

During the first experiments (P1 and P2) the number of passes during the first three 5-minute test periods was considerably less than during control periods, and decreased still further during subsequent periods of observation. The sharks seemed to be quite wary of the presence of the bag and tended to circle more and more in the end zones. This was the case particularly with the larger of the two grey sharks, which avoided the test area to a much greater extent than the smaller one when the bag was present.

During later experiments (P3 and P4), the sharks were still startled by the initial presence of the bag but became adjusted to it more

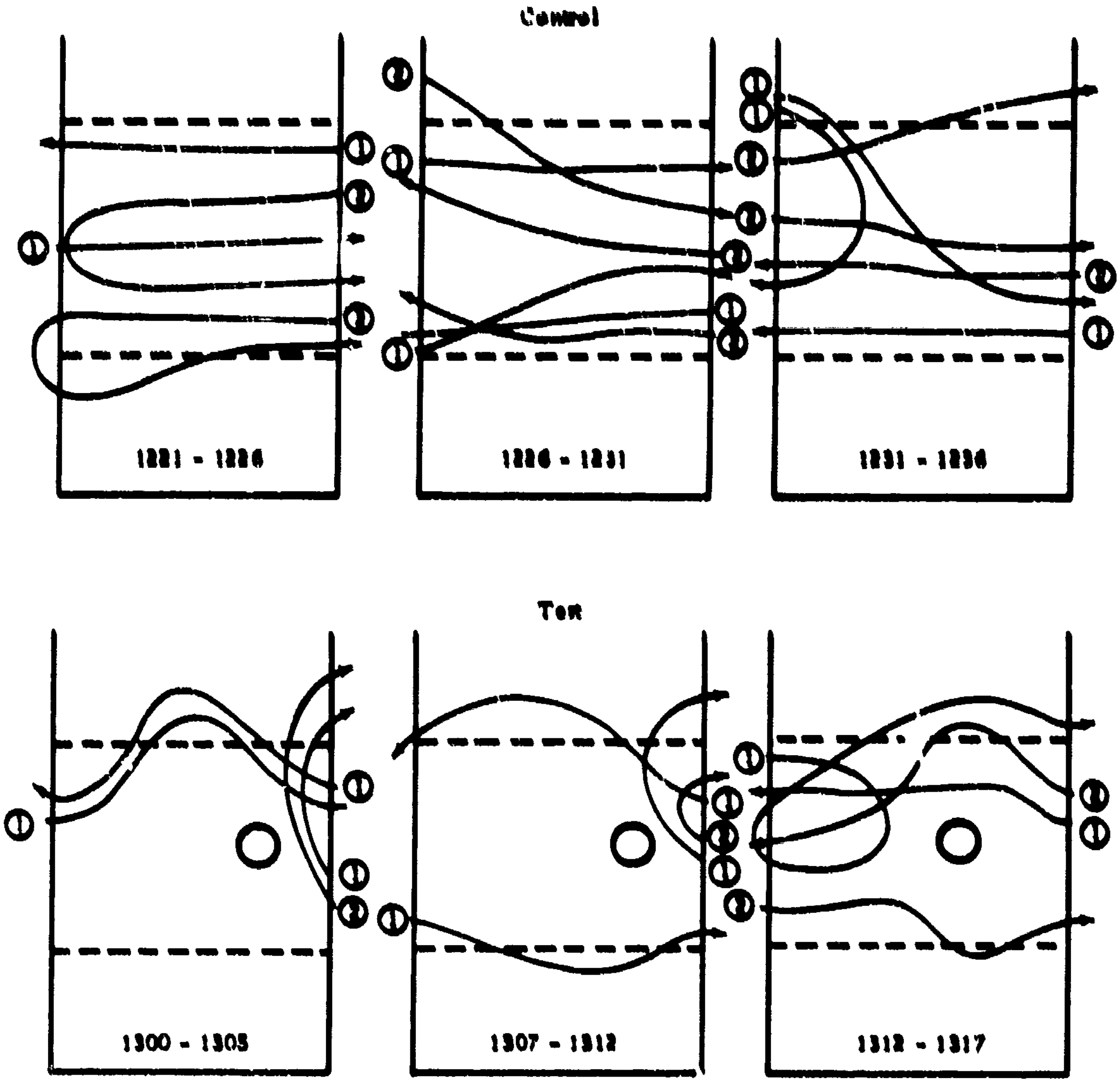

FIG. 2. Diagram Showing Movements of Sharks Through Test Area During Control and Test Conditions of Exp. 2.

quickly. They continued to veer around the bag when swimming in mid-water, but sometimes passed beneath it, usually veering slightly, when swimming deep. The deep passes sometimes brought them within 4 or 5 feet of the bottom of the bag.

The responses to the pink bags generally were similar. However, it was our impression that when swimming in mid-water, the sharks approached somewhat closer (8 to 10 feet) to the pink bag than to the grey bag (10 to 12 feet). This seemed to be the case in comparing the results of P1 (grey) and P2 (pink) and also in comparing the results of P3 (pink) and P4 (grey), when the order of testing was reversed.

Responses to bags with chum.

After the foregoing observations had been made in experiments P2 and P4, pieces of cut fish were thrown from the tower as close as possible to the bag. The sharks immediately were attracted by the splash of the chum, approached the surface with dorsal fin above water, and excitedly circled the bag in a feeding frenzy. Generally they would take the chum when it was at least a foot away from the bag. When it was less than one foot, a shark would dash in on a collision course with the bag, but then would abruptly veer at a distance of about one foot without taking the bait. In veering, the shark sometimes would hit the bag with pectoral fins, body or tail. On one occasion (P4) a shark rammed the bag with its snout and then circled it closely attempting to devour the bait but not succeeding.

In this last instance, the shark's teeth apparently caught the bag, for it suffered a jagged 8-inch-long rip on the side just below the cuffs. However, the bag previously had been torn near the bottom when it was dragged across the coral. This made it flaccid, hence more susceptible to snagging on the shark's teeth.

There was no noticeable difference in the sharks' behavior toward the grey and pink bags during the chumming operation.

Response to Bags with Fish Attached.

One fish was tied to a line to dangle against the side of the bag after chumming in Experiment P4, and six fish were similarly tied to dangle around the outside of the bag before chumming in Experiments

P5 and P7. In P4 and P5, within a few minutes after the bag with attached fish was placed in position, the sharks sensed the odor, surfaced and excitedly circled the bag. However, they did not approach closer than about two feet and at no time did their body come in contact with the bag. The action died down soon and the sharks ignored the bag. In P7, again with six fish tied to the bag, the sharks were swimming on the bottom and did not pick up the scent.

In all three experiments, chum then was tossed from the tower, landing near the bag with its attached fish. The sharks immediately became exicted, circled the bag and fed voraciously on the chum. They approached close enough to the bag to take the single attached fish in P4 and one of the six attached fish in P7. During the feeding frenzy the sharks frequently brushed against the side of the bag with their body and fins, causing it to sway back and forth and change in shape. This caused the attached fish to oscillate; sometimes they would be flat against the side of the bag and sometimes they would be projected a distance of about 8 inches from it. The sharks appeared to take the two fish when they were angled out from the side of the bag.

The flaccid grey bag used in Experiment P4 suffered an additional rip during the above action. The turgid pink bag used in Experiments P5 and P7 suffered no damage from the sharks.

Swimmer in bag.

At the close of the above experiments the pink bag was taken to a spot outside the pond and entered by one of us (Daniels). Once in the bag, pressure of his foot or knee caused the seam to rip apart along the side of the bag. The seam is too weak and the fabric of both bags, particularly the grey one, seems to be too filmsy for use under rugged survival conditions.

SECTION II - LAGOON TESTS

MATERIAL

Facilities.

During July, 1966, the behavior of sharks to plasticized bags was observed in Eniwetok lagoon. All observations were made from or around a barge anchored about 300 yards to the southwest of island Rex (Jieroru) (Fig. 3). During the first week of observations (July 5 to July 12) the barge was anchored from one end only and swung some distance from side to side. During the second and third weeks of observations (July 14 to July 25), the barge was anchored at both ends and remained more or less in a fixed location.

Observations were made from the barge deck and from two underwater viewing chambers, one attached to the barge and the other to a raft (Fig. 4). Shortly after it was put into operation, the raft chamber separated from the raft as a result of wave action, and sank. Consequently most of the observations were made from the barge chamber. In addition some observations were made from a cage tied to the side of the barge at the water surface (Fig. 6).

The underwater viewing chamber attached to the barge placed one observer about six feet below the water surface. Three observation ports allowed vision in three directions. The largest port (about 9 x 20 inches) faced the experimental area, where the bags were introduced and held in the water.

Throughout the experimental period, water visibility generally was good, ranging from 50 to more than 125 feet (estimated). Weather usually was clear, with scattered clouds and an occasional shower. Water temperature (85 deg. F) was taken once at 1430 hrs., July 28.

Bags.

The supplied bags were of two sizes, large (37-inch diameter) and small (24-inch diameter). They were of eight colors (white yellow, flesh, grey, green, red, blue, black). In addition was supplied a single green bag (37-inch diameter) having a silvery foil around its outside. This bag is called a "chrome" bag in this report.

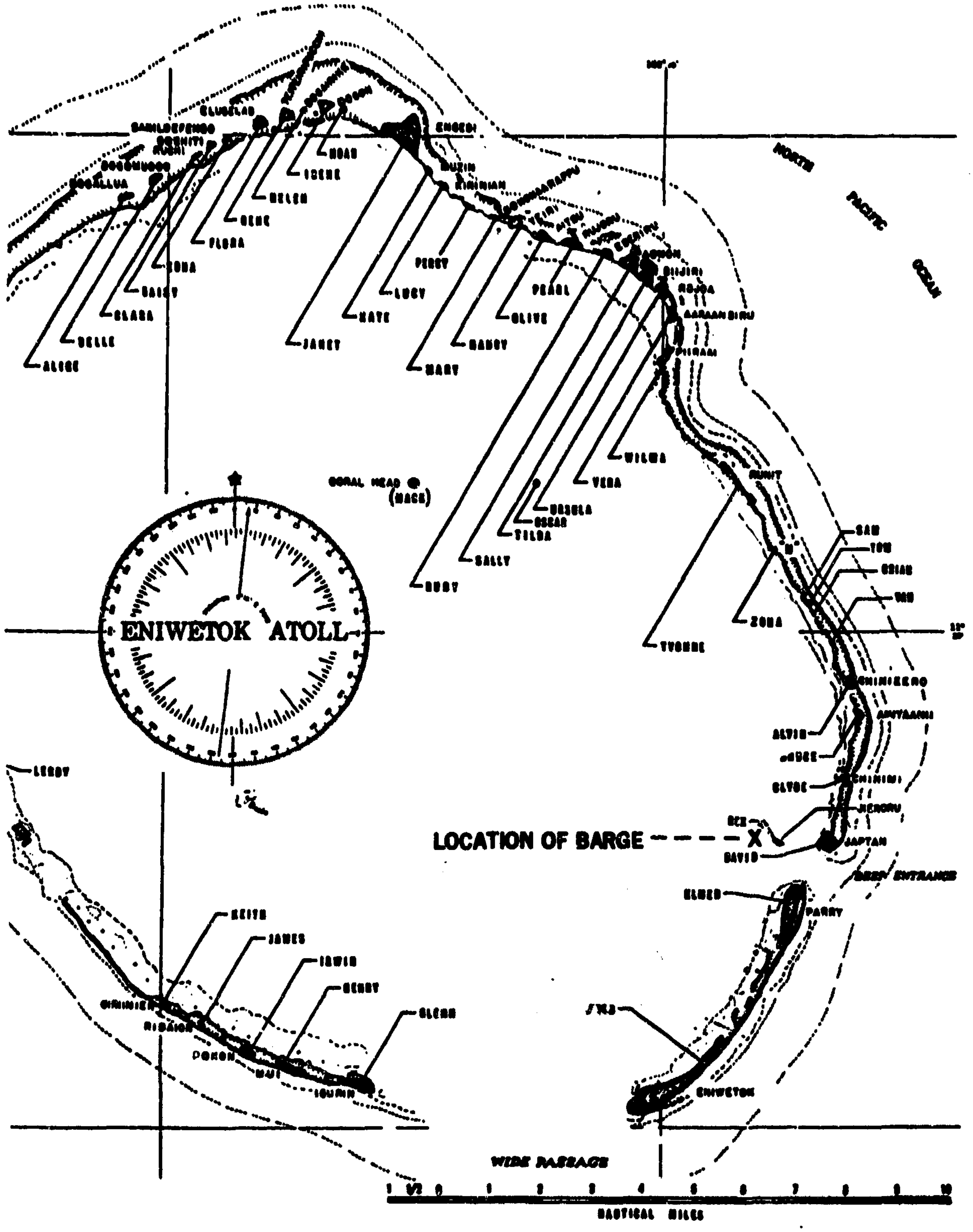

FIG. 3. Map of Eniwetok Atoll Showing Location of Barge.

FIG. 4. Foreground, Viewing Chamber Before Attachment to Barge. Background, Shark Cage and Viewing Chamber Attached to Raft.

FIG. 5. Experimental Situation With Two Bags, Large and Small, Showing Viewing Chamber Attached to Barge.

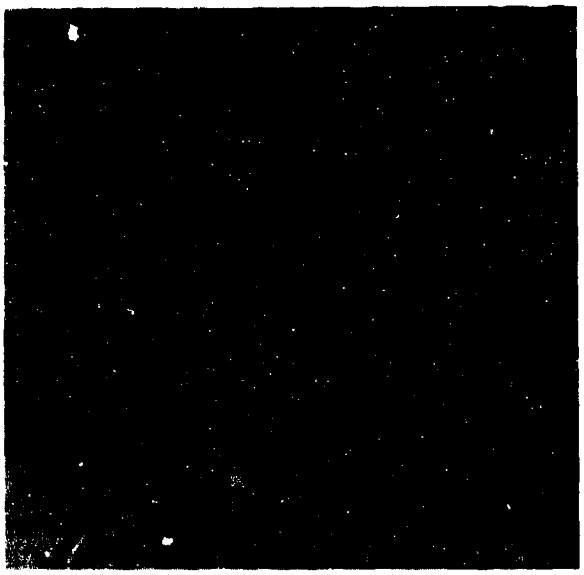

FIG. 6. Shark Cage, As Seen From Viewing Chamber Attached to Barge.

FIG. 7. Experimental Situation With Two Bags, Large and Small, Showing Bait Dangling at the Surface and One Shark Attacking Bait and Another Near the Large Bag.

Bags other than white, black and chrome were matched with color charts in "A Dictionary of Color" by Maerz and Paul (2nd edition, McGraw-Hill Book Company, 1950). The color samples most nearly matching the bags are listed in Table 2.

Reflectivity of bags of different colors was measured in air and in eight feet of water in Eniwetok lagoon, with the results shown in Table 3.

Transmission of light through bags of different colors was measured in air, with the results shown in Table 3.

Sharks.

Three species of sharks commonly appeared during the observation periods, the whitetip shark *Triaenodon obesus* (family Triakidae), the blacktip shark *Carcharhinus melanopterus* (family Carcharhinidae) and the grey shark *Carcharhinus menisorrah* (family Carcharhinidae). Only one other species of sharks, possibly either *Hemigaleops fosteri* or *Carcharhinus brachyurus* (family Carcharhinidae), was ever sighted, and that was only briefly during the last part of the last experiment.

Table 2. Color samples matching the colors of bags (from Maerz and Paul, "A Dictionary of Color," 2nd edition, 1950, McGraw-Hill Book Company).

Bag Color	Sample Color
Yellow	Plate 17, K-1
Flesh	Plate 10, A-7
Grey	Plate 44, A-4
Green	Plate 25, J-10
Red	Plate 1, J-5
Blue	Plate 33, I-12

Table 3. Measurements of reflectivity and transmission of light by bags of different colors. All measurements are in foot-candles (fc) and are averages of two trials with those in air rounded off to the nearest foot-candle and those in water to the nearest 10-foot candles. Percentage of reflectivity (%) is based on all three of the listed values in air for a bag of a given color.

Bag Color	Reflectivity for incident light of					Transmission for incident light of
	25 fc (Air)	40fc (Air)	130fc (Air)	% (Air)	800+fc (Water)	120fc (Air)
White	11	17	48	39	320	10
Yellow	7	13	35	28	270	67
Flesh	7	12	35	28	310	21
Grey	6	10	30	24	140	0
Green	3	5	13	11	160	58
Red	2	3	12	8.7	70	33
Blue	2	3	8	6.7	100	33
Black	1	2	5	4.1	40	0

METHODS

Bag Reflectivity.

Reflectivity was measured in air and in eight feet of water in Eniwetok lagoon, with a Wesson illumination meter (model 756). In air, measurements were obtained for each color of bag (37-inch diameter) under three levels of incident light (25, 40 and 130 foot-candles). In water, measurements were obtained for each color of bag (37-inch diameter) in bright sunlight at 1300 hours.

For air measurements a bag of a given color was unfolded and spread over a table 2½ feet square, so that two layers of bag material covered the table. Overhead illumination consisted of two and three fluorescent tubes (for incident light of 25 and 40 foot-candles), or three fluorescent tubes supplemented by an incandescent spotlight (for incident light of 130 fc). Light sources were four feet above the table.

Reflected light was measured by the meter facing downward one foot above the center of the table. Incident light was measured by the meter facing upward while placed upon the black bag in the center of the table.

Air measurements were repeatable within 5% or less and those given in Table 3 are averages of two trials. Water measurements were variable by as much as a factor of two, owing to light fluctuation in the water medium. One source of fluctuation was surface waves. These caused a constantly changing pattern of light and dark on the illuminated surfaces of the bag. Another source was the attitude of the bag and the amount of glare reflected from its surface. A third source was variability in bag fabric, some being relatively opaque (white, flesh, grey and black), others relatively translucent (yellow, green, red and blue).

In order to eliminate some of the variability due to transmitted light and glare, measurements were taken from the sunlit side of the bag and under conditions of minimum glare, two feet below the water surface and one foot from the bag. Under these conditions water measurements were repeatable within 25% or less for two trials, the averages of which are given in Table 3.

In addition, light intensity was measured along horizontal (190 foot-candles), 45-degree inclined (800+ foot-candles) and 90-degree vertical (800+ foot-candles) axes (Table 3).

The relative brightness of the different colored bags can be assumed to be that shown in the air measurements with white being the brightest, followed by yellow, flesh, grey, green, red, blue and black in that order. Measurements in water agree reasonably well with those in air.

Transmission of light through bags.

Transmission of light through bags of different colors was measured in air by placing the bags on a table with overhead lights four feet above. The lights consisted of three fluorescent tubes and one incandescent spot-light. Incident light of 120 foot-candles was measured by the meter facing upward in the center of the tabletop. Transmitted light was measured by the meter in the same location facing upward directly beneath one layer of bag material. Measurements were repeatable within 5% or less and those given in Table 3 are averages of two trials.

Experiments with bags.

The first series of experiments (L1-L10) were performed with a single large bag (37-inch diameter) in the water. Shortly after the bag introduction a quantity (20 to 30 pounds) of chopped fish (surgeon fish, sea bass, snappers, etc.) in a wire basket was lowered into the water. Thereafter ensued a period of waiting for the sharks to appear. When they appeared additional chopped fish piece by piece was thrown into the water to tempt the sharks to approach the bag, where their reactions to the bag could be observed.

Certain problems appeared early in the course of these experiments and their solutions had some bearing on the experimental results. The problems concerned mainly (a) securing of the bag, (b) behavior of the sharks toward the chum.

Strong currents and high winds usually were present in the study area and it was impossible to secure the bags to the barge with a single or double loop of rope around them or a loop through them. As a result of wind and current, deformation of the bag resulted from a loop around it and eventually the bag would slip free altogether. Any loop through the bag weakened it and resulted in extensive tearing. Better but still unsatisfactory results were obtained by using a double loop attached to a line weighted by a lead brick. The horizontal axis of the double loop

prevented the bag from slipping out, but the loop still seriously deformed the bag. Clearly some sort of internal support was called for and a braced, ring-like, sheet-metal band was made the same diameter as the bag and inserted just below the inflatable cuff (Fig. 8). The ring had additional metal pieces soldered to it to form a partial groove around its out-side circumference. With the ring in place, a double loop of rope around the outside of the bag could be tightened in the partial groove. This harness worked well when attached to the weighted line. However, the ring in response to the motion of the bag tended to slip out of the loop and sink to the bottom of the bag.

It turned out that this condition was quite satisfactory if the ring were attached to the double loop on the outside. Inside the bag, the ring with its attached line absorbed sufficient amount of the strain to prevent serious bag deformation by the double loop on the outside. As a result, most of the bags were harnessed in this way and attached to a line weighted by a lead brick dangling about three feet below the level of the bag bottom. The ring inside the bag and the line in the water did not seem to influence shark behavior. In contrast the lead brick (the size of a house brick) was of considerable interest to the sharks, for they often bumped it with their snout or took it partially into their mouths and bit it.

The behavior of the sharks toward the chum was highly variable, depending on several factors. For example, initially it was difficult to tempt sharks to the surface. Leaving the wire basket containing chopped fish on the surface gave poor results. The sharks were not attracted to it, for they habitually stayed deep near the bottom. Thus the wire basket was lowered to the bottom or as deep as practicable. This situation gave better results and more sharks were attracted to the wire basket.

Throwing chopped fish piece by piece into the water sometimes was effective in tempting sharks to come to the surface in the vicinity of the bag. As noted earlier, however, the barge initially was free to swing side to side some distance. The result of this swing was that the barge sometimes was over a reef and water 6 to 20 feet deep and sometimes over a channel and water in excess of 150 feet deep. In most cases throwing chopped fish into the water resulted in its accumulating on the bottom. When the water was relatively shallow, this was advantageous, for sharks accumulated in an area relatively near the bag to

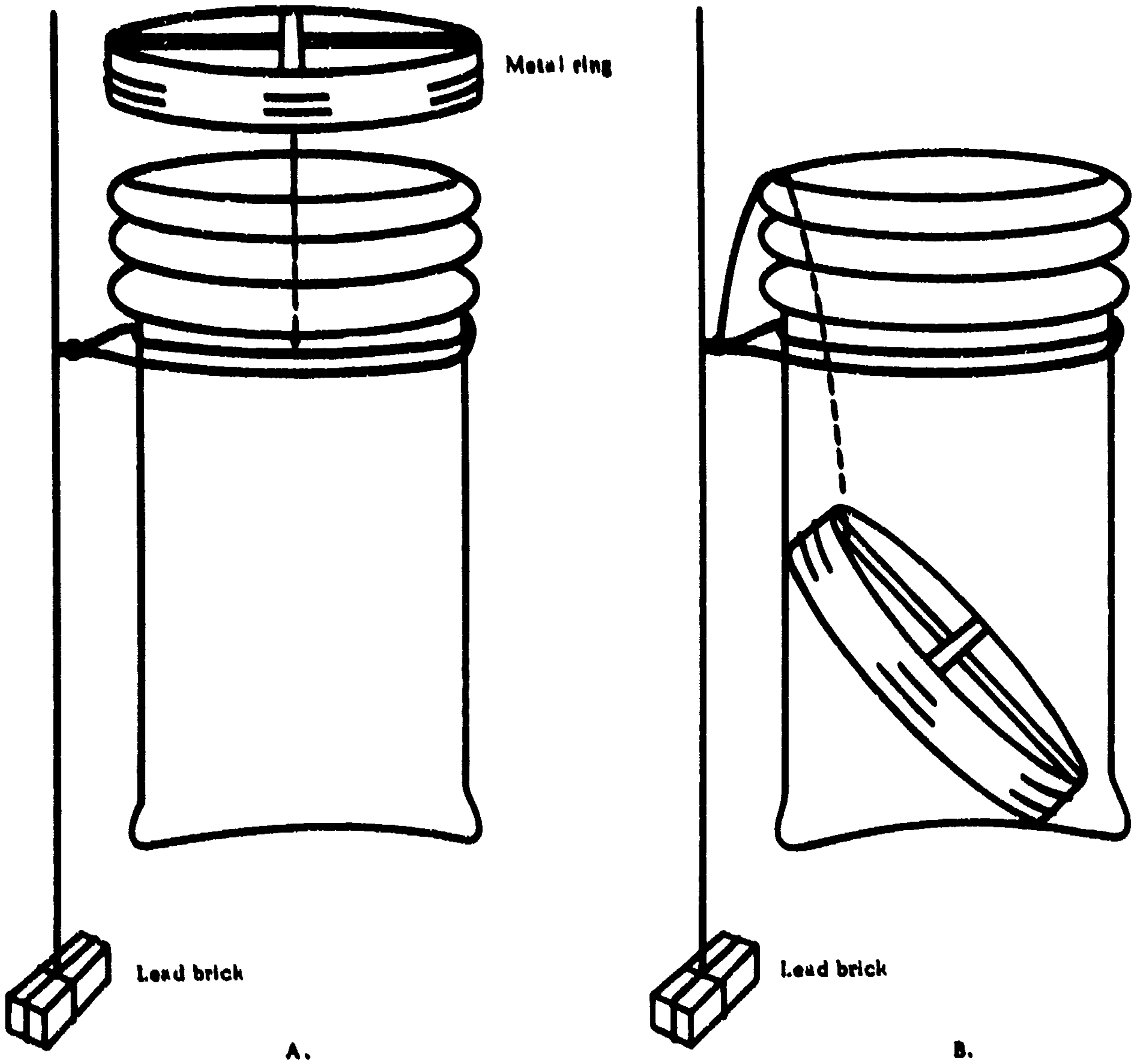

FIG. 8. Diagram Showing Method of Fastening the Bag (A.) Intended Position of Metal Ring (B.) Usual Position of Metal Ring.

eat the fish. When the water was relatively deep, this was disadvantageous, for the sharks accumulated in an area relatively far from the bag.

These circumstances suggested that better results could be obtained over the reef area in relatively shallow water, and the barge consequently was anchored from both ends over shallow water about 20 feet deep. The results were as expected and sharks tended to accumulate in the study area in relation to the amount of chopped fish thrown in. However, it still proved difficult to tempt the sharks to approach the surface. Consequently the chumming technique was modified. Whole fish rather than chopped fish were used and these were attached to a line so that they could be raised from the bottom when the sharks attacked them. This technique gave very good results and was employed during the later (11 to 20) experiments. A typical series of events might be as follows - (a) placement of bag(s) in water; (b) placement of wire basket containing 20 to 30 pounds of chopped fish on or near the bottom; (c) lowering near or to the bottom 30 to 60 pounds of whole fish attached to a line so that they could be raised.

The first sharks to be seen in the area on any given day usually were whitetips. They typically took much interest in the wire basket, often bumping it or biting it. After some minutes grey sharks generally appeared, often around the wire basket. Eventually the grey sharks found the whole fish and began to feed upon them. An attack upon the fish by one shark usually would result in the attraction to the fish of the other sharks in the area. At this point the fish slowly were raised toward the surface. As the fish were raised, the grey sharks often seemed to lose track of them, and would return to the bottom, apparently to hunt for food. In such a case, the fish were returned to the bottom. Shortly thereafter, the sharks again would find them, and then the fish slowly would be raised. This procedure usually was successful in tempting the sharks to the surface near the bags (Figs. 9 and 10). Once at the surface the sharks were allowed to feed upon the whole fish. In addition, chopped fish usually was thrown into the water close to the bags.

While the sharks were at the surface in the vicinity of the bags, their behavior was observed and certain aspects of it counted - (a) the approaches within one foot of a bag; (b) the brushes against a bag by the fins or body of a shark; (c) bumps and bites on a bag; (d) bumps and bites on a lead brick. Contacts with the wire basket also were counted. At the same time, a running census of the shark population in the experimental area was maintained.

FIG. 9. Sharks Attacking Bait in Mid-Water, With a Lead Brick Visible in Background.

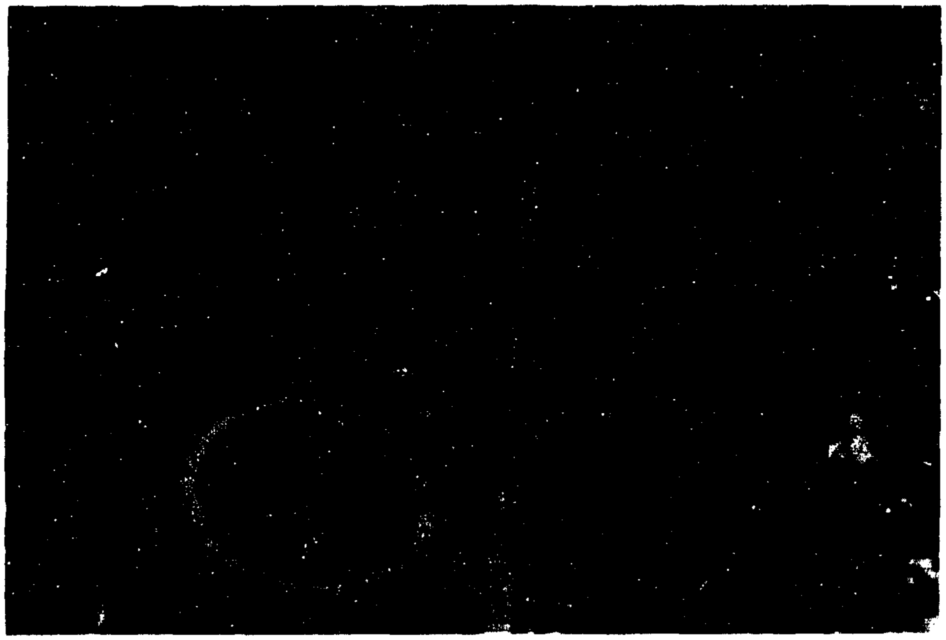

FIG. 10. Experimental Situation Showing a Shark Passing Near a Large Bag.

RESULTS

Experimental results are summarized in Tables 4 through 10 (at the end of this section). Experiments L1 to L10 and L19 include those experiments done during daylight hours with a single large bag (Table 4). Experiments L11 to L18 include those done during daylight hours with two bags, large and small, usually of the same color. Experiment L20, with large black and large white bags, was done during late afternoon and evening hours.

Response to a Single Bag.

During the first week of the experiments, it soon became apparent that most of the sharks induced to come to the surface were not noticeably attracted or repelled by any of the bags regardless of their color. The attitude of most of the sharks toward the bags seemed to be indifferent. In general sharks would not approach within one foot of the bag except to eat chopped fish thrown into the water near it. Then the sharks never exhibited any hesitation in approaching the bags. Occasionally a shark would wander into the area from the upstream side, circle the bag at a distance of 3 to 5 feet and swim away. More rarely a shark would take a greater interest in the bag, inspect it at a close distance, bump it or brush against it, apparently even when not motivated by food.

It sometimes was impossible during the course of an experiment to tempt the sharks to the surface because of their predilection to hunt for food along the bottom. This was true especially for the whitetips and blacktips. The grey sharks were the most easily tempted to the surface. Consequently they approached the bags more frequently than either the whitetips or blacktips, even though the greys were not always the most abundant species in the study area. The greys, however, generally seemed to be the most aggressive species. On some occasions when grey sharks were relatively few or absent altogether, whitetips could be induced to approach the surface in the vicinity of the bag. Almost never, however, did whitetips take an interest in the chopped fish thrown into the water until the fish came to rest upon the bottom. Unlike that of the greys, the behavior of the whitetips was never observed to become frenzied. The blacktips during these experiments could never be induced to approach the surface, for they always stayed deep along the bottom.

Occasionally contacts occurred between sharks and bag. These were either brushes with the body or fins, or bumps with the snout, as when the shark directly approached the bag until his snout bumped it. Rarely was a shark seen to attempt to bite the bag. Sometimes one seemed to intend biting the bag but missed contact with it (abortive bite). On two occasions one shark actually bit the bag on one corner along the bottom edge. No visible damage could be seen to any of the bags resulting from contact between sharks and bag.

The bumping of the bag seemed to be a kind of testing procedure on the part of the sharks. In any case, anything they might have learned from bumping the bag did not stimulate them to attack it. The sharks also and more frequency bumped the brick weighting the line to which the bag was attached. In general, it seemed that once a shark bumped the brick, he did not then attempt to bite it. What he learned from bumping it possibly inhibited further attack. However, the brick was bitten several times.

Response to two bags of the same color and different sizes.

During these experiments the shark population generally was much greater, for the location of the barge was fixed over shallow water and sharks tended to accumulate in the area. Shark behavior was very similar to that observed in experiments with single bags. In general, sharks appeared to be indifferent to the bags and would approach them without hesitation to take food.

Most of the contacts between sharks and bags were "brushes." The sharks were tempted to the surface by raising to the surface whole fish between the two bags, separated from one another by about 10 feet. Behavior of the sharks, when they followed the fish to the surface, tended to become frenzied, and many contacts between shark and bag occurred at this time when the sharks were competing with one another to attack the fish.

In only one instance during the experiments was the bag actually bitten, on one corner along the bottom edge. Upon close examination of the bag, no teeth marks could be seen.

Response to bags in the evening.

During Experiment L20, a large black and a large white bag were tested from 1630 to 2015 hours. There were few approaches to either bag until dark (about 1945), although there were many sharks in the area. After dark a 375-watt photospot bulb was used to illuminate the experimental area. During this time, the behavior of the sharks radically changed. They surfaced and swam in the area of the bags. attacking several dead fish dangling at the water surface for the remainder of the experiment. Their number was estimated to be more than 25. The number of approaches to the bags accumulated so rapidly that the number of contacts between shark and bag could not be counted, but the sharks were observed repeatedly to brush against the white bag (at least 20 times). No contact between sharks and the black bag was seen.

Response to a human in the bag.

After Experiment L18, one of us (Daniels) entered the small flesh-colored bag, while the bag was in the water near the shark cage and sharks in the area. Some difficulty was encountered in tempting the sharks to the surface, and only one *bona fide* approach to the bag was made by a grey shark. This resulted in a brush contact to the bag which was not felt on the body of the person inside. The experiment lasted about 20 minutes without further incident.

Rates of Approach and Contact between Grey Sharks and Bags.

Rates of approach to and contact with bags of different colors are summarized in Tables 8 to 10 for grey sharks. Data for whitetip and blacktip sharks are too few to permit analysis. Apparent correlations exist between (a) bag reflectivity and the rate of approach (Fig. 11), (b) bag reflectivity and the rate of contact, expressed either as contacts per shark-minute (Fig. 12) or as contacts per approach (Fig. 13).

The reflectivity of the chrome bag was not measured but obviously was much higher than that for the other bags (Table 3). A value of 80% arbitrarily was given to the chrome bag for purposes of graphical analysis.

To permit comparison between approach and contact rates, a logarithmic transformation was applied to the data. This also involved the

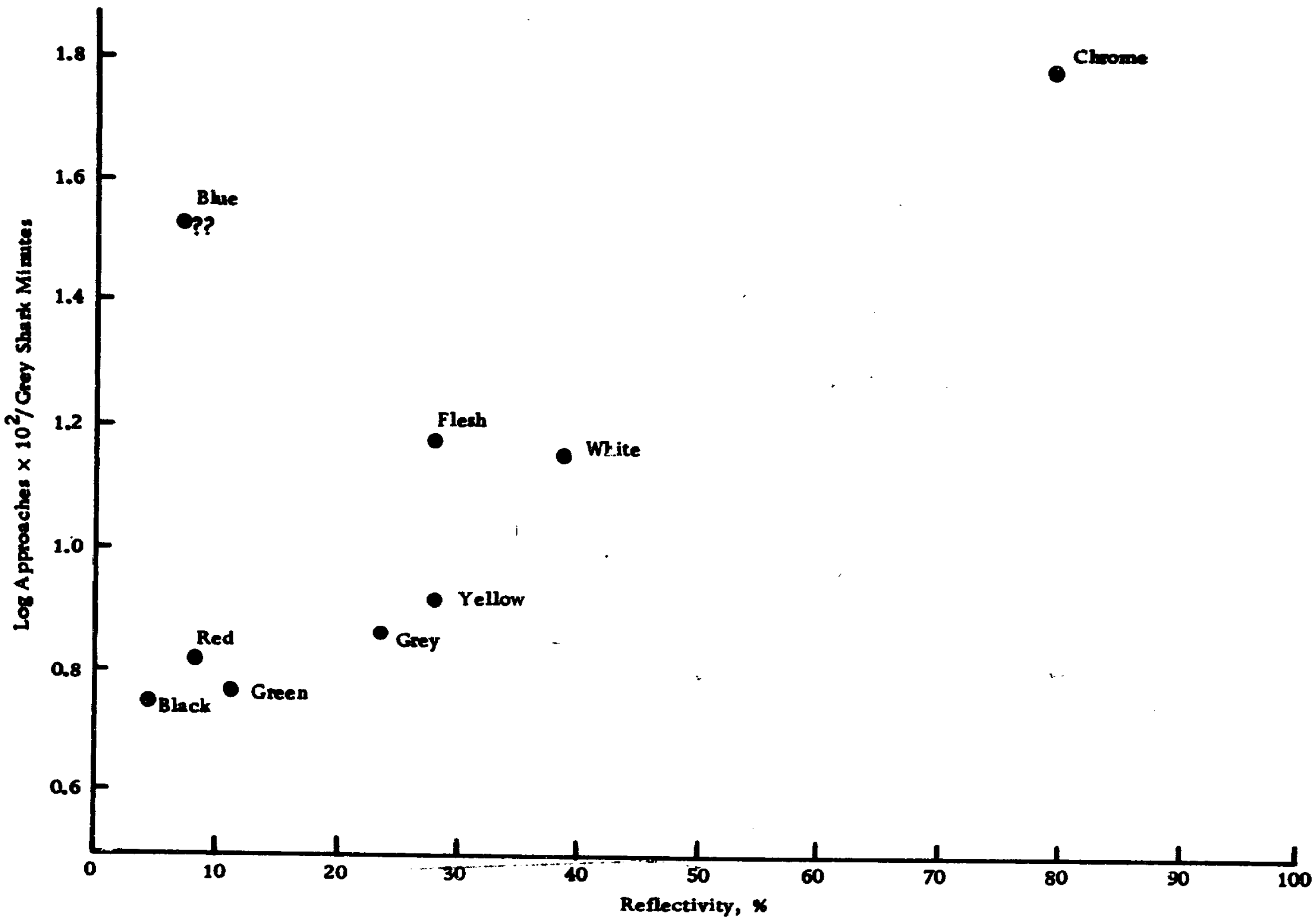

FIG. 11. Relation Between Rate of Approach by Grey Sharks and Bag Reflectivity. There are relatively few data for the blue bag.

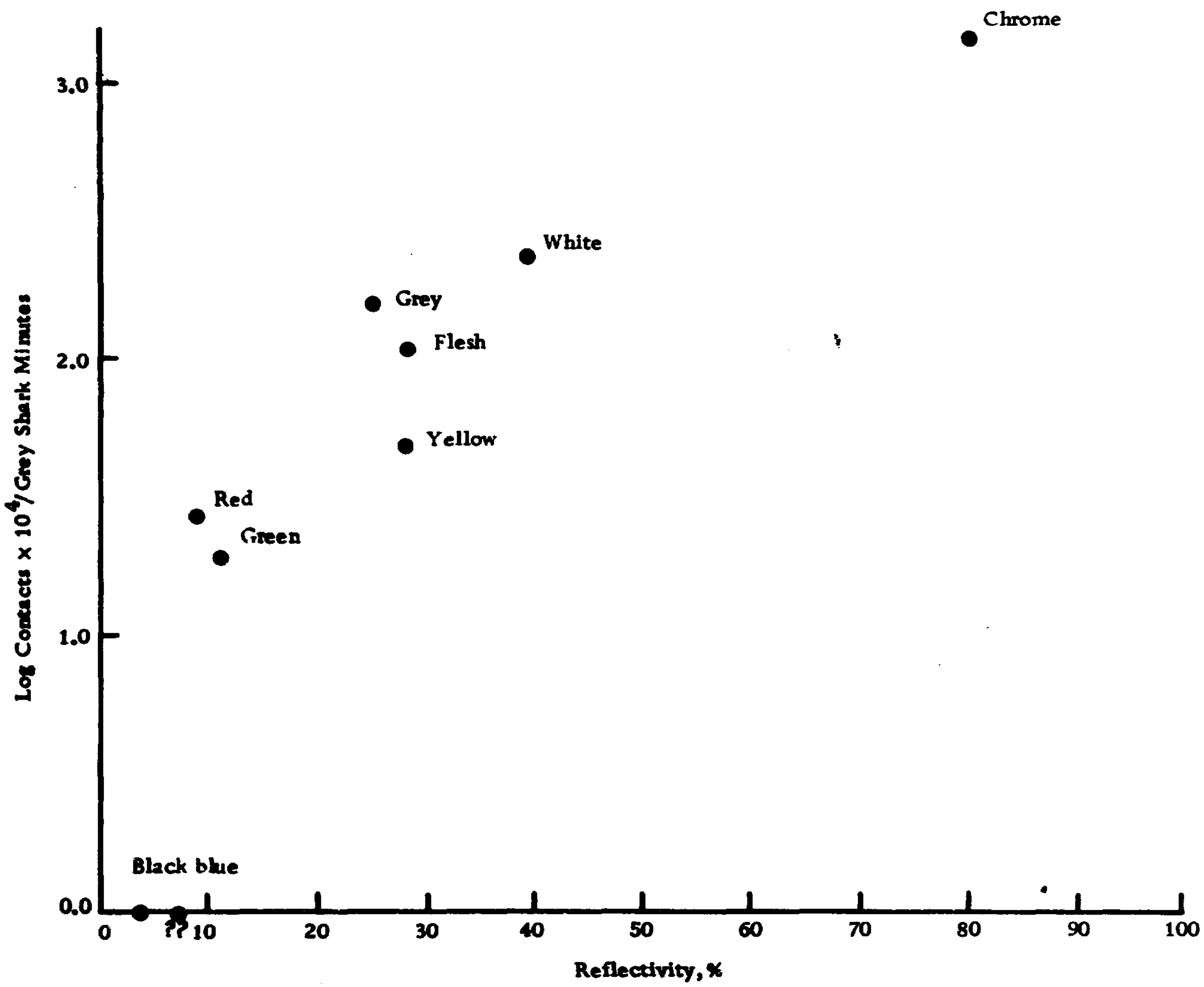

FIG. 12. Relation Between Rate of Contact by Grey Sharks and Bag Reflectivity. There are relatively few data for the blue bag.

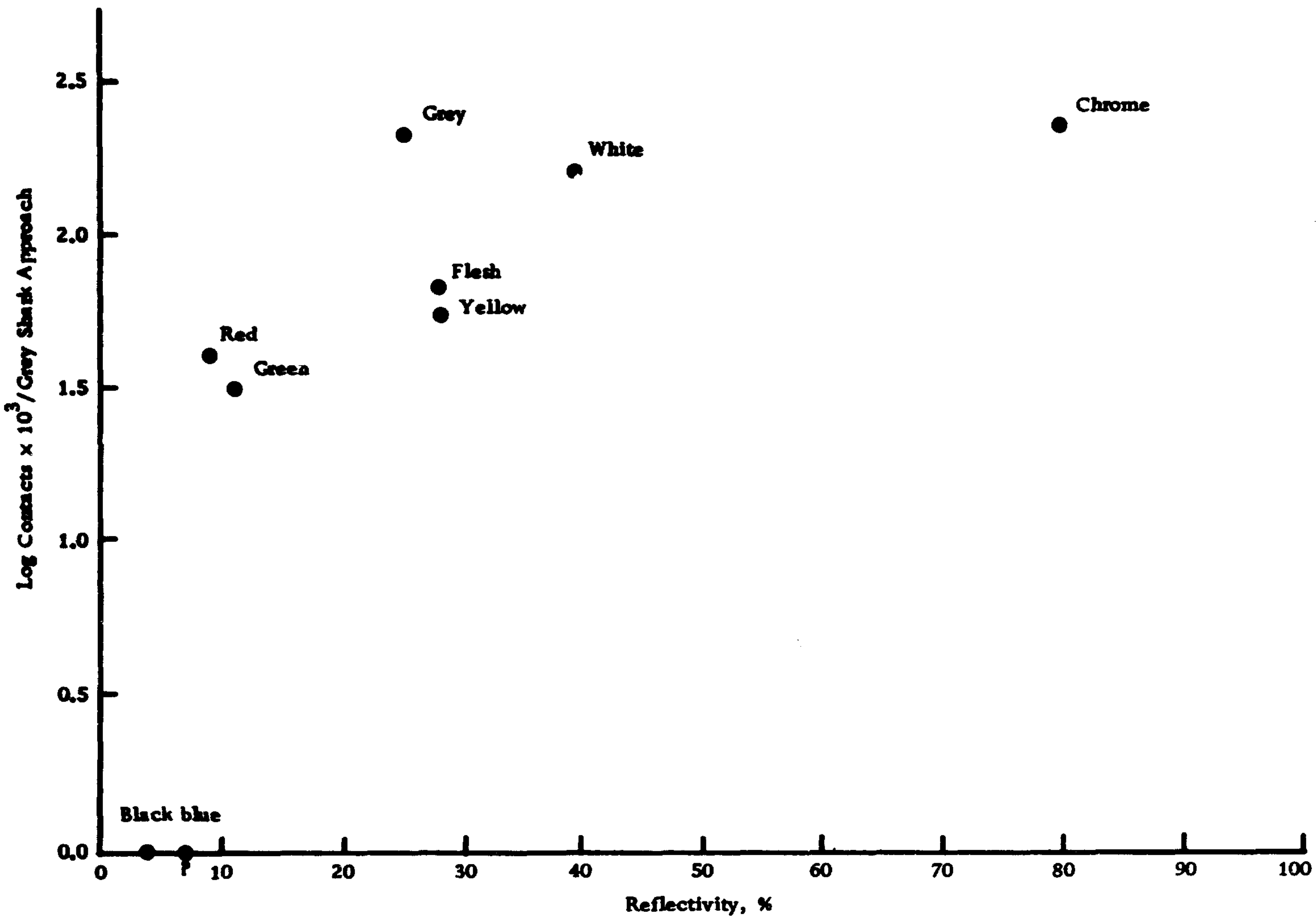

FIG. 13. Relation Between Contacts per Approach by Grey Sharks and Bag Reflectivity. There are relatively few data for the blue bag.

addition of one unit to the contact rates to eliminate zeros for the blue and black bags (Tables 9 and 10). The transformed contact rate for the blue bag is probably somewhat unreliable, for it is based on few data. The apparently divergent approach rate for the blue bag (Table 8 and Fig. 11) may be unreliable for the same reason.

Data for the black bag include those of Experiment L20. These were accumulated at twilight. Owing to the prevailing dim light conditions and the intense activity of the sharks at this time, the data may be less reliable than those of other experiments. No contacts were noted during this time despite over 80 approaches within one foot of the black bag. It is possible however that a small number of contacts were overlooked. Data for the white bag, on the other hand, do not include those of Experiment L20. Activity around the white bag was so intense, with so many approaches, that it was impossible to keep an accurate count of contacts. An estimated minimum number of contacts during this time was 20.

Behavior of Whitetip and Blacktip Sharks toward Bags.

Whitetip sharks exhibited much the same behavior toward the bags as the grey sharks. They occasionally showed some curiosity, and sometimes brushed against the bags when they apparently were not motivated by food. They also on occasion bumped the bags with their snout. During Experiment L7, two abortive bites were made by one large (about 6-foot) whitetip.

The blacktip sharks often were present in the experimental area, but almost never left the bottom. During Experiment L20, at twilight the blacktip activity seemed to increase and six approaches to the bag were made at this time by blacktips.

DISCUSSION

Size of Bags and Sharks.

Behavior of sharks toward large and small bags was not noticeably different. The number of approaches and contacts were somewhat higher for the large bag, but this circumstance probably resulted from the experimental situation, for the large bag generally was on the downstream side of the dangling bait. The bait, as it was raised, tended to be swept by the current toward the large bag rather than toward the small one.

The sharks that participated in the experiments ranged from about two to seven feet, with the majority between five and six feet. In general their response to the bags was favorable, for they did not attack the bags and never visibly damaged them, even though the bags were bitten three times. The sharks seemed to be more interested in smaller objects, such as the lead bricks. The sharks bumped and bit the lead bricks more often than they did the bags. When they did bite the bag, they did so at one of the two corners along the bottom edge. These corners seemed to provide a more conveniently biteable shape than the rest of the bag.

The size of the bags in relation to the size of the sharks may have been an important factor in these experiments. If so, the behavior toward the bags of some of the larger sharks, for example the tiger shark Galeocerdo cuvieri, ranging in excess of 15 feet, or the great white shark Carcharodon carcharias, ranging in excess of 30 feet, might be substantially different. The experiments reported here were not designed to explore this problem.

Color of Bags.

Because no difference could be detected in shark behavior toward bags of different sizes, data for different sizes were combined for bags of the same color. Apparent are positive correlations between brightness of the bag (reflectivity) and rates of approach to and contact with the bag. Regardless of the nature of the contact no apparent damage due to sharks ever was inflicted upon the bags. However, it would seem that bags of low reflectivity, e.g., black, should be the more appropriate for the designed purpose of the bags.

Of some interest in this regard is the behavior of sharks toward small, bright objects. By accident, some observations of this behavior were made during the lagoon tests. As a result of discarding some refuse from the barge, two or three small (4 oz.) shiny tin cans came to rest on the lagoon bottom in the experimental area. During the course of some of the experiments, grey sharks seemed to be interested in the cans, for they often circled about them, picked them up in their mouth, afterward dropping them back to the bottom. It seemed that the sharks were attracted to the cans by the shiny metallic luster.

Transparency of Bags.

No experiments were made to determine the response of sharks to transparent versus opaque bags. However, some of the supplied bags were translucent to varying degrees (Table 3). As shown in Fig. 14, a swimmer's mask, body and limbs readily can be seen under direct sunlight through the translucent green bag. His movements within such a bag might visually attract a shark. An opaque bag would eliminate this possibility.

Movement of Bags.

Because of the relatively strong water currents and wind in the experimental area, the bags had to be secured to the barge to prevent their drifting away. The result of securing the bags by a line was a certain amount of bag movement due to the wind and current as the bag strained on the line. Underwater observations of the bag revealed that it constantly was changing shape, according to the stresses along its surface.

It had been planned to induce water movement within the bag, for example by a plunger device, to simulate movement by a person within the bag. Some attempt was made to do this, with the result that the movement of the bag was not significantly increased. For this reason, further attempts to induce additional movement of the bags were abandoned.

A more direct approach to the problem was attempted, that of exposing a person within the bag to shark attack. As already discussed, Daniels entered the flesh-colored bag while sharks were feeding in the area. He remained in it for about 20 minutes. During this period

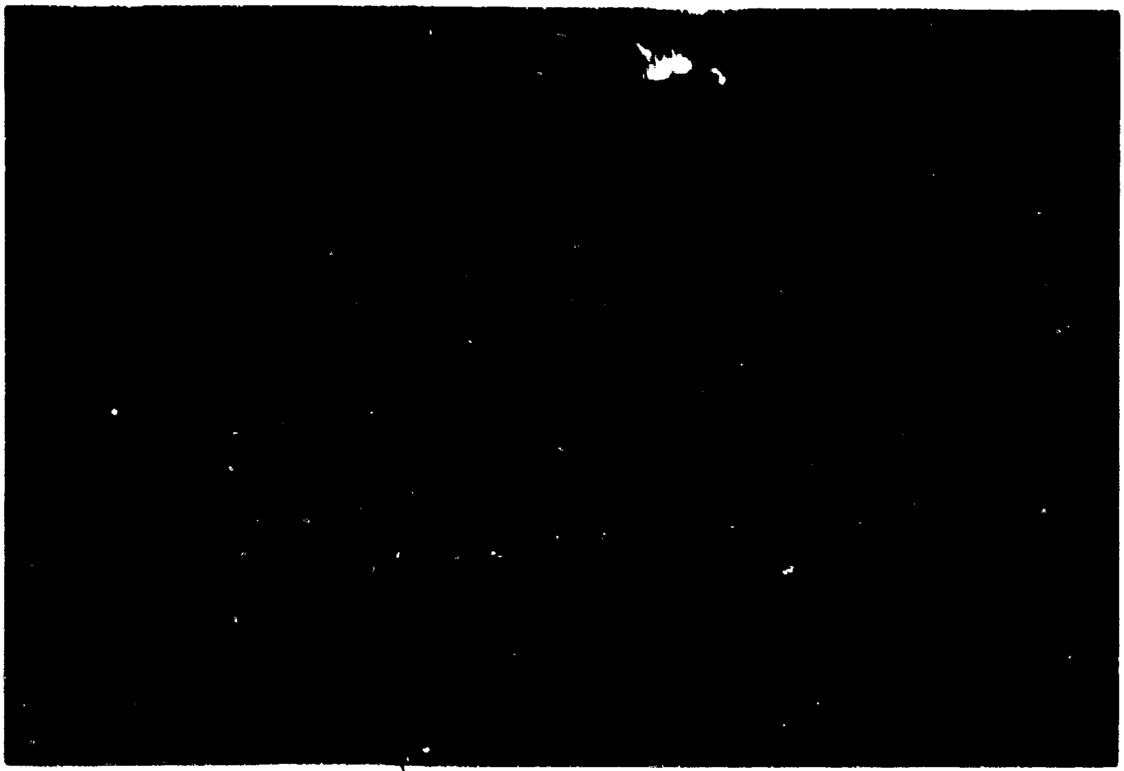

FIG. 14. A Large Green Bag With a Swimmer Inside, Showing the Degree of Bag Transparency.

FIG. 15. Chrome Bag at the Termination of Experiment L19, Showing Fragmentation of Foil.

there was only one close approach by a grey shark, resulting in a brush contact with the bag, which was not felt by Daniels. Apparently the sharks were not attracted to the bag by his body movements.

Endurance of Bags.

All of the bags used in these experiments were undamaged by the sharks when the bags were removed from the water and inspected. Damage to the bags, when it did occur, resulted from the harness used to secure them to the barge. An exception was the chrome bag. This bag had an outer layer of metallic foil around it. This foil started to fragment soon after the bag was placed in the water. By the end of Experiment 10 much of the foil had come off the bag. However, enough of the foil remained to allow another experiment with the chrome bag. At the end of Experiment 19, somewhat more than half of the foil remained.

Table 4. Experiments with single bags (daylight hours).

Exp. No.	Date	Bag Color	Experiment Time	Duration (minutes)	Sharks Present (minutes)	SHARK MINUTES[1] GREY	WHITETIP	BLACKTIP	TOTAL
L1	7/5	Yellow	1400-1445	45	45	90 (2)	10 (1)	0 (0)	100 (3)
L2	7/7	Black	0920-1105	105	27	108 (5)	25 (4)	0 (0)	133 (9)
L3	7/7	White	1215-1300	45	30	30 (1)	30 (2)	7 (1)	67 (3)
L4	7/7	Grey	1330-1515	105	31	46 (2)	0 (0)	0 (0)	46 (2)
L5	7/8	Grey	0910-1225	195	85	15 (1)	22 (2)	0 (0)	37 (2)
L6	7/8	Flesh	1305-1500	115	115	30 (3)	232 (4)	230 (4)	492 (11)
L7	7/9	Green	1120-1230	70	45	35 (1)	185 (6)	0 (0)	220 (7)
L8	7/9	Blue	1320-1500	100	85	40 (1)	270 (3)	210 (4)	520 (8)
L9	7/11	Red	0855-1445	350	96	30 (1)	54 (2)	17 (3)	101 (4)
L10	7/12	Chrome	0910-1450	340	17	16 (1)	1 (1)	1 (1)	18 (1)
Subtotals				1470	576	440 (5)	838 (6)	465 (4)	1743 (11)
L19	7/25	Chrome	1245-1305	20	20	180 (9)	80 (4)	80 (4)	340 (17)
Totals				1490	596	620 (9)	918 (6)	545 (4)	2083 (17)

[1] Shark minutes = the number of sharks multiplied by the minutes present. Sharks included in this calculation are only those during the running census observed to come within the experimental area, that is within the visibility range of the observer, and to take chum, search for food, or approach within a few feet of the bag. Numbers in parentheses are the maximum numbers of sharks present at any one time.

Table 5. Experiments with two bags (daylight and evening hours), mostly of two sizes, large and small.

Exp. No.	Date	Bag Color Large	Small	Experiment Time	Duration (minutes)	Sharks Present (minutes)	SHARK MINUTES GREY	WHITETIP	BLACKTIP	TOTAL
L11	7/14	Flesh	Flesh	1000-1500	300	51	30 (3)	79 (3)	30 (2)	139 (5)
L12	7/15	White	Black	0915-1345	270	90	172 (6)	109 (2)	57 (3)	338 (7)
L13	7/16	Red	Red	0940-1500	320	185	367 (4)	296 (4)	76 (4)	739 (8)
L14	7/18	Green	Green	0925-1155 1345-1410	175	175	538 (10)	313 (4)	135 (5)	986 (11)
L15	7/19	Grey	Grey	0945-1145 1205-1240	190	182	694 (11)	344 (6)	133 (2)	1171 (17)
L16	7/20	Yellow	Yellow	1040-1320	160	160	704 (12)	484 (4)	194 (3)	1382 (19)
L17	7/22	White	White	1040-1125 1145-1225	105	105	467 (8)	387 (4)	261 (2)	1115 (14)
L18	7/25	Flesh	Flesh	0945-1125	100	100	529 (11)	310 (5)	145 (3)	984 (19)
L20	7/25	White Black	- - - - - -	1630-2015	225	225	1534 (25)	269 (3)	672 (6)	2475 (25)
Totals					1845	1274	5035 (25)	2591 (6)	1703 (6)	9329 (25)
Single bag experiments					1490	596	620 (9)	918 (6)	545 (4)	2083 (17)
Grand totals, all experiments					3335	1870	5655 (25)	3509 (6)	2248 (6)	11412 (25)

Table 6. Contacts between grey and whitetip sharks and (a) chum basket, and (b) lead bricks. No contacts were noted for blacktip sharks.

Exp. No.	BASKET CONTACTS Grey	BASKET CONTACTS Whitetip	BRICK CONTACTS Bumps Grey	BRICK CONTACTS Bumps Whitetip	BRICK CONTACTS Bites Grey	BRICK CONTACTS Bites Whitetip
L1	0	0	0	0	0	0
L2	5	0	10	0	3	0
L3	0	0	0	0	0	0
L4	0	0	0	0	0	0
L5	0	0	3	0	2	0
L6	0	0	0	2	0	0
L7	0	6	2	4	1	1
L8	0	2	5	2	1	0
L9	7	0	0	0	1	2
L10	0	0	0	0	1	0
L11	6	0	1	1	0	3
L12	9	1	5	0	2	0
L13	10	6	7	0	1	0
L14	17	5	4	0	1	0
L15	1	0	13	0	0	0
L16	7	9	12	0	2	0
L17	5	28	5	1	0	0
L18	17	6	14	0	2	0
L19	0	0	8	0	2	0
L20	22	3	20	0	2	0
Totals	106	66	109	10	21	6

Table 7. Approaches to bags by grey, whitetip (WT) and blacktip (BT) sharks, and contacts between bags and grey and whitetip (WT) sharks. No contacts were noted between bags and blacktip sharks. Abortive bites are not included in total contacts.

Exp. No.	Bag Size	Bag Color	APPROACHES WITHIN ONE FOOT Grey	WT	BT	Total	CONTACTS WITH BAG Brush Grey	Brush WT	Bump Grey	Bump WT	Bite Grey	Bite WT	ABORTIVE BITE Grey	ABORTIVE BITE WT	Total Contacts
L1	L	Yellow	26	0	0	26	0	0	0	0	0	0	0	0	0
L2	L	Black	13	0	0	13	0	0	0	0	0	0	0	0	0
L3	L	White	4	0	0	4	0	0	0	0	0	0	0	0	0
L4	L	Grey	0	0	0	0	0	0	0	0	0	0	0	0	0
L5	L	Grey	27	0	0	7	5	0	3	0	0	0	1	0	8
L6	L	Flesh	0	0	0	0	0	0	0	0	0	0	0	0	0
L7	L	Green	0	17	0	17	0	6	0	0	0	0	0	2	6
L8	L	Blue	14	8	0	22	0	0	0	2	0	0	0	0	2
L9	L	Red	20	4	0	24	1	0	0	0	0	0	0	0	1
L10	L	Chrome	12	1	0	13	1	0	0	0	2	0	2	0	3
L11	S	Flesh	0	13	0	13	0	4	0	5	0	0	0	0	9
L11	L	Flesh	0	4	0	4	0	0	0	2	0	0	0	0	2
L12	S	Black	1	0	0	1	0	0	0	0	0	0	0	0	0
L12	L	White	0	0	0	0	0	0	0	0	0	0	0	0	0
L13	S	Red	9	0	0	9	0	0	0	0	0	0	0	0	0
L13	L	Red	22	0	0	22	1	0	0	2	0	0	0	0	3
L14	S	Green	36	3	0	39	1	0	0	0	0	0	0	0	1
L14	L	Green	30	1	1	32	1	0	0	0	0	0	0	0	1

Table 7. (Cont'd) Approaches to and contacts with bags by sharks.

Exp. No.	Bag Size	Bag Color	APPROACHES WITHIN ONE FOOT Grey	WT	BT	Total	CONTACTS WITH BAG Brush Grey	WT	Bump Grey	WT	Bite Grey	WT	ABORTIVE BITE Grey	WT	Total Contacts
L15	S	Grey	31	2	0	33	3	0	0	0	0	0	0	0	3
L15	L	Grey	49	0	0	49	12	0	0	0	0	0	0	0	12
L16	S	Yellow	40	1	0	41	2	0	0	0	0	0	0	0	2
L16	L	Yellow	57	0	0	57	2	0	2	0	1	0	0	0	5
L17	S	White	81	0	2	83	13	0	2	0	0	0	0	0	15
L17	L	White	71	0	0	71	9	0	1	0	0	0	0	0	10
L18	S	Flesh	83	0	0	83	0	0	4	0	0	0	0	0	4
L18	L	Flesh	95	0	0	95	0	0	8	0	0	0	0	0	8
L19	L	Chrome	109	0	1	110	19	0	7	0	0	0	2	0	26
L20	L	Black	89	0	1	90	0	0	0	0	0	0	0	0	0
L20	L	White	234	3	6	243	20+	0	0	1	0	0	0	0	21+
Totals			1153	57	11	1221	90+	10	27	12	3	0	5	2	142+
Totals for large versus small bags of same color –															
Small bags			280	19	2	301	19	4	6	5	0	0	0	0	24
Large bags			324	5	1	330	25	0	11	4	1	0	0	0	41

Table 8. Total grey shark-minutes and total approaches by grey sharks to bags of different color (including the white bag of experiment 20). The approach rate equals the number of approaches multiplied by 100, with the product being divided by the number of shark-minutes.

Bag Color	Shark-minutes	Approaches	Approach Rate	Log_{10} Approach Rate
Chrome	196	121	61.7	1.79
White	2670	390	14.6	1.16
Yellow	1498	123	8.10	0.91
Flesh	1148	178	15.5	1.18
Grey	1449	107	7.38	0.87
Green	1111	66	5.94	0.77
Red	764	51	6.67	0.83
Blue	40	14	35.0	1.54
Black	1814	103	5.68	0.75

Table 9. Total grey shark-minutes and total contacts between grey sharks and bags of different colors (excluding the white bag of experiment 20). The contact rate equals the number of contacts multiplied by 10,000, with the product being divided by the number of shark-minutes. One unit is added to each contact rate to remove zeros for blue and black bags.

Bag Color	Shark-minutes	Contacts	Contact Rate + 1	Log_{10} Contact Rate + 1
Chrome	196	29	1481	3.18
White	1136	25	221	2.34
Yellow	1498	7	47.7	1.68
Flesh	1148	12	106	2.03
Grey	1449	23	160	2.20
Green	1111	2	19.0	1.28
Red	764	2	27.1	1.43
Blue	40	0	1.0	0.00
Black	1814	0	1.0	0.00

Table 10. Total approaches and total contacts to bags of different colors (excluding the white bag of experiment 20) by grey sharks. The contact rate equals the number of contacts multiplied by 1000, with the product being divided by the number of approaches. One unit is added to each contact rate to remove zeros for blue and black bags.

Bag Color	Approaches	Contacts	Contact Rate + 1	Log_{10} Contact Rate + 1
Chrome	121	29	241	2.38
White	156	25	161	2.21
Yellow	123	7	57.9	1.76
Flesh	178	12	68.4	1.84
Grey	107	23	216	2.33
Green	66	2	31.3	1.49
Red	51	2	40.2	1.60
Blue	14	0	1.0	0.00
Black	103	0	1.0	0.00

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

1. We believe the plasticized bags are far superior to U. S. Navy Shark Chaser, chemical repellents and electrical devices which we have tested for protecting persons from shark attack. When not motivated by food, both the captive and the free-swimming sharks with which we worked tended to avoid the bags. Only rarely were free-swimming sharks seen to circle the bag at sufficiently close range to brush against it. Even when motivated by food, the sharks did not attack the bag (except for its bottom corners) although they did bump or brush against it with their bodies when feeding on chum close to the bag. When the bag was occupied by a person (in only one test) in the presence of free-living sharks motivated by food, the sharks did not attack the bag. A grey shark brushed against it but the contact was not felt by the person.

2. The bags used in the lagoon tests (but not those used in the pond tests) were of sufficiently strong material and construction to withstand the strain of a person entering the bag and moving around in it. Also, they were sufficiently strong to resist damage when hit or brushed by the sharks. Strength of material is vitally important, for if a hole or rip develops not only will odors be dispersed to the surrounding water but also the bag will become flaccid and more susceptible to damage from shark contact.

3. The smaller (24-inch) bag was just as effective as the larger (37-inch) bag. It has the obvious advantage of forming a smaller and lighter package.

4. We recommend investigation of the possibility of producing a bag with a rounded bottom, preferably without seams. On a few occasions the sharks bit the bottom corners of the present bag. Although the bag was not damaged, it might have been torn or perforated by more aggressive shark action. This "bite-hold" should be eliminated.

5. The color of the bag (per se) seems unimportant, but the reflectivity of the bag seems very important. We recommend bags of low reflectivity (e.g., black). There were relatively few approaches and no contacts with the black bag during daytime tests. There were relatively few approaches and apparently no contacts with the black bag

during an evening test. Both approach rate and contact rate tended to increase with increasing bag reflectivity, reaching maximum values with the highly reflective chrome bag.

6. Our experiments were not designed to compare opaque and translucent bags independently of color and reflectivity. However, it seems that under daylight conditions the movements of a person in the bag readily can be seen by the shark through the translucent bag and that these movements might invite attack. Accordingly, we recommend that the bags be made of an opaque material.

7. The sharks with which we worked were of medium size (mostly five to seven feet). There is still the unresolved question of whether larger free-living sharks, such as the tiger, mako and great white, would attack the bag.

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	Naval Ordnance Systems Command Naval Material Command Washington, D.C. 20360

13. ABSTRACT

Plasticized bags were tested and found to offer advantages over chemical repellents and electrical devices that were tested for effectiveness in protecting humans against shark attack, including the chemical substance presently issued by the Navy. When not motivated by food, both captive and free-swimming sharks tended to avoid the bags. Only rarely were free-swimming sharks seen to circle a bag at sufficiently close range to brush against it. Even when motivated by food, the sharks did not attack the bag, although they did bump or brush against it with their bodies when feeding on chum close to the bag. (In one instance, a bag bottom corner was bitten; however, this was during a period of competition among sharks for a fish suspended between two bags.) When the bag was occupied by a human in the presence of free-swimming sharks (which occurred in only one test), the sharks did not attack the bag. A grey shark brushed against it, but the contact was not felt by the human occupant.

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UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Sharks						
Protective devices						
Ocean survival						

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